

CThW4 Fig. 3 Experimental results for the 40 Gbit/s to 10 Gbit/s demultiplexing. (a) 40 Gbit/s data stream; (b) 10 Gbit/s clock; (c) demultiplexed pulses at 10 Gbit/s.

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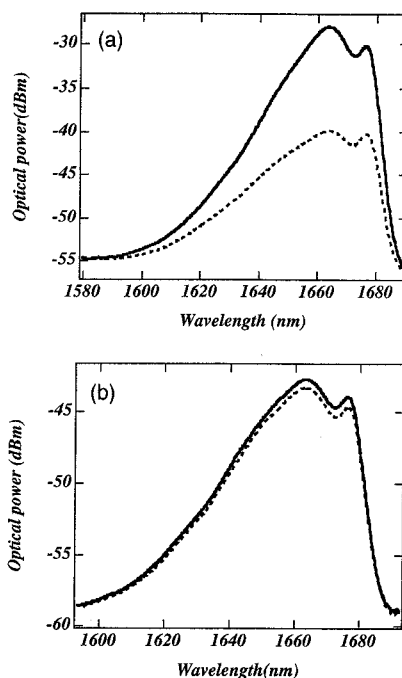
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CThW5 5:30 pm

Effect of randomly varying birefringence on the Raman gain in optical fibers

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The Raman gain coefficient for parallel polarized pump and Stokes waves is nearly 10 times larger than that for perpendicularly polarized waves. For the long interaction lengths relevant to optical communication, the Raman gain in a fiber with random birefringence becomes the average of the parallel and perpendicular gain coefficients, independent of the input polarization.¹ However, the same may not hold for fiber Raman amplifiers, which are typically a few kilometers long. Here we show that the length over which the Raman gain for copropagating signals becomes independent



CThW5 Fig. 1 Effect of polarization mode dispersion on the polarization sensitivity of Raman gain. The 1550-nm pump pulses have 10 W peak power and 10 ns duration. The pump wave's state of polarization adjusted for maximum (solid curve) or minimum (dashed curve) Raman output. (a) Corning SMF 28 fiber, length = 2.3 km, polarization mode dispersion = 0.05 ps/km^{1/2}; (b) standard AT&T fiber, length = 2 km, polarization mode dispersion = 0.90 ps/km^{1/2}.

of input polarization is determined by polarization mode dispersion.

We measured the forward stimulated Raman scattering power in two ~2 km fiber spools with vastly different polarization mode dispersion. We put 10-ns pulses with 10 W peak power into the fiber samples and measured the average Stokes power at the output as we varied the input pump's state of polarization. The samples, a 2.259-km spool of Corning SMF28 fiber and a 2-km spool of standard AT&T telecommunication had measured polarization mode dispersions $D_p = 0.05$ ps/km^{1/2} and $D_p = 0.90$ ps/km^{1/2} respectively. Figure 1 shows the average Stokes power at the output of each fiber for two different input states of polarization of the pump. The Stokes power changes by 16 dB in the Corning fiber as the input polarization is varied to maximize or minimize the output Stokes power, corresponding to a 33% change in the effective Raman gain coefficient at the peak. In contrast the output Stokes power varies by 0.6 dB corresponding to a 2.3% change in the gain coefficient for the AT&T fiber.

Since the pump and Stokes pulses are at different wavelengths, their polarizations drift randomly away from one another. After a characteristic length, l_c , which we call the two-wavelength polarization decorrelation length, the two states of polarization become uncorrelated. The polarization decorrelation length of a single frequency has been calculated previously.^{2,3} Generalizing this result to the case of a copropagating pump and Stokes at frequencies

ω_p and ω_s , we expect the two-wavelength polarization decorrelation length to be $l_c \sim 4/(\omega_p - \omega_s)^2 D_p^2$. Here $D_p = \sqrt{\langle \Delta\tau^2 \rangle}/L$ is the polarization mode dispersion, $\sqrt{\langle \Delta\tau^2 \rangle}$ is the differential group delay, and L is fiber length. The polarization sensitivity of Raman gain depends on the ratio of the effective Raman interaction length to the decorrelation length. In our case, the relevant Raman interaction length is $L_{\text{eff}} = (1 - e^{-\alpha L})/\alpha$, where α is the absorption coefficient and L is the fiber length. The Raman gain is independent of the input polarization for $L_{\text{eff}} \gg l_c$. Using the measured values of D_p for the two fibers we obtain $l_c = 320$ m for the Corning fiber and $l_c = 1.2$ m for the AT&T fiber. Assuming a simple model of equal segments of fiber with constant length l_c and randomly varying gain, we predict the gain variation to be $\Delta g/g = \sqrt{l_c}/l$. This equation predicts a variation $\Delta g/g \sim 37\%$ for the Corning fiber to be compared with the measured value of 33%, and $\Delta g/g \sim 2.4\%$ for the AT&T in good agreement with the measured value of 2.3%.

We will present measurements in unspooled fibers as well as results of detailed simulations. We will also discuss the impact on the polarization sensitivity of backward-pumped fiber Raman amplifiers.

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CThW6

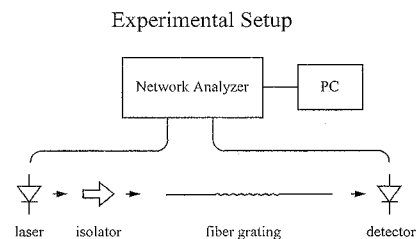
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Increase in semiconductor laser modulation response by FM to AM conversion in transmission through fiber grating

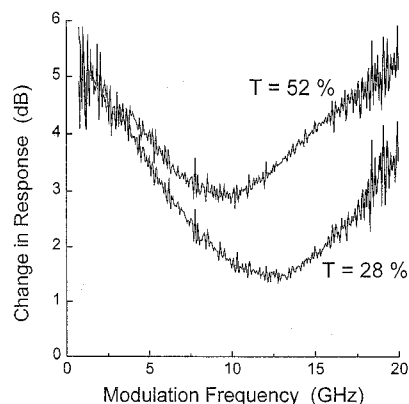
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An unchirped fiber Bragg grating (FBG) was recently used in transmission to compensate for 72 km of standard dispersive fiber.¹ Propagation through a dispersive medium will change the modulation response of a semiconductor laser,^{2,3} as will transmission through any frequency filter, as a consequence of laser chirp. We have used an unchirped FBG in transmission to increase the modulation response of a directly modulated DFB laser by 3 to 5 dB at modulation frequencies up to 20 GHz. The group delay dispersion of the signal introduced by the grating was negligible.

Our experimental setup is depicted in Fig. 1. A single-mode DFB laser temperature-tuned around 1540 nm was biased 75 mA above threshold and directly modulated through a microwave probe. The output was sent through an optical isolator and launched into a fiber pigtail, through a fiber grating, and onto a fast photodiode detector. The grating was 1 cm



CThW6 Fig. 1 Schematic of experimental setup.



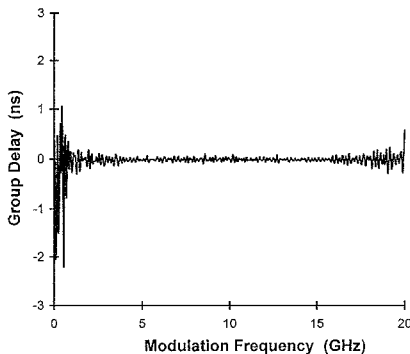
CThW6 Fig. 2 Change in AM response of laser produced by fiber grating, versus modulation frequency, with laser frequency tuned to two different positions along the transmission spectrum.

in length, with no intentional chirp or apodization, and had a maximum reflectivity of 92.5% and a FWHM of 0.21 nm. An HP 2865 network analyzer calculated the system response at swept frequencies from 50 MHz to 20 GHz.

The laser response without the grating was subtracted from the system response after transmission through the grating. Figure 2 shows the change in the AM signal produced by the FBG. When the laser was tuned to a grating transmission of 52% (in DC optical power), the FBG increased the signal by 3 to 5 dB at all frequencies up to 20 GHz. The optical modulation depth increased also, by a factor of 3.4 at its largest. When the laser was tuned to a grating transmission of 28%, the AM signal increased between 1.6 dB and 5 dB. This is an increase in the modulation depth by a factor of 6.4 at its largest, from 8.5% to 54%. The change in the response was a strong function of the laser frequency, as operating at a different part of the transmission spectrum will produce no change or a decrease in the signal.

The group delay added to the signal by the grating is shown in Fig. 3, minus a constant fiber-length delay. The data was limited by noise, but there is no discernible slope, indicating negligible dispersion suffered by the AM signal. The fluctuations in both figures are likely attributable to the poor temperature stability of our laser cooler.

The increase in the laser response is predicted theoretically and depends on the amount of laser chirp. We determined the adiabatic and transient chirp parameters of our laser at the same operating conditions used



CThW6 Fig. 3 Group delay added to AM signal by transmission through fiber grating (minus a constant fiber-length delay) versus modulation frequency.

above, by measuring the laser modulation response after propagation through standard dispersive fiber.⁴ A theory will be presented explaining the observations in terms of the laser FM, which is attendant on the AM, being converted into AM by dispersion in the fiber grating.

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CThX

4:30 pm–6:30 pm
Room 327

Integrated Devices and Optical Materials

Won-Tien Tsang, *Lucent Technologies, President*

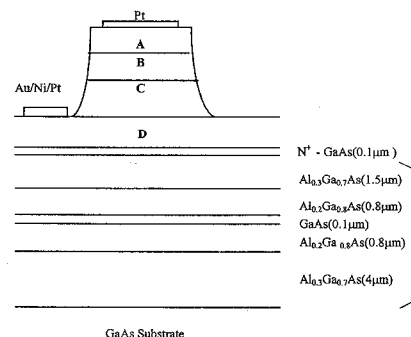
CThX1

4:30 pm

InGaAs p-i-n photodiodes on AlGaAs/GaAs waveguides and monolithic integration applications

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Monolithic integration of photodetectors with both passive and active optical waveguide components has applications in local area networks. For long distance fiber optical communication systems, high-speed and large bandwidth InGaAs p-i-n photodetectors can meet requirements for operation in excess of 1–10 Gbits/s. Presently, GaAs is the most highly developed compound semiconductor, and the technology for monolithic integration of InP-based optoelectronic devices on InP substrates is less developed than that of GaAs electronic integrated circuits. Therefore, it is highly desirable to develop techniques for the monolithic integration of InGaAs photodiode devices operating in the 1.0–1.6 μm wavelength range with AlGaAs/GaAs waveguides and circuits. Among the various integration approaches, the vertical integration method, which stacks two optoelectronic device structures one on top of the other, is one of the simplest.¹ The technique we use, including a thin InP buffer layer between an $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ photodiode and an AlGaAs waveguide using solid source MBE and etched total-internal-reflection mirrors by chemically assisted ion beam etching



Double Heterostructure	Homojunction
A: P - 0.15 μm $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$	P - 0.12 μm $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$
B: P - 0.1 μm InP	N ⁻ - 1.7 μm $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$
C: N ⁻ - 1.8 μm $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$	N ⁺ - 0.11 μm $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$
D: N ⁺ - 1.7 μm InP	N ⁺ - 1.25 μm InP

Five-Layer Waveguide

CThX1 Fig. 1 Schematic cross sections of InP/ $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ /InP double heterostructure and $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ homojunction photodiodes.